FURTHER CONSIDERATIONS ON THE ORIGIN OF THE HIMALAYA MOUNTAINS AND THE PLATEAU OF TIBET.

(PLATES XXIII–XXXIII AND XXVII *bis* AND XXXI *bis*.)

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(*Read April 18, 1913.*)

I. Introductory Remarks.

The four memoirs dealing with the cause of earthquakes, mountain formation and kindred phenomena connected with the physics of the earth, which the writer had the honor to communicate to this Society in the years 1906–08, and have published in the *Proceedings,* have laid the foundations of a new theory of the physics of the earth's crust. The new theory already is widely adopted by the most eminent investigators, and the purpose of the present paper is merely to add a final confirmation of some interest.

During the past five years the writer's attention has been so fully occupied with the problems of cosmogony that the problems relating to geogony, or the formation of the earth, have been left largely in abeyance; and yet some new light has been shed on them, especially by the researches showing that the lunar craters are due to impact, and thus in no way similar to terrestrial volcanoes, as was so long believed.

Quite recently it was thought worth while to reëxamine the phenomena of the earth's crust, in the light of the new science of cosmogony, resulting from the researches of the past five years. For in studying the problem of the origin of the Himalayas and the plateau of Tibet some important considerations were brought out that were not included in my former papers, and thus it seems advisable to place them on record as confirming and extending my former investigations.

Moreover, the subject of the origin of the Himalayas is attracting attention abroad. Apparently without knowledge of my work* Colonel Sidney G. Burrard, R.E., F.R.S., surveyor-general of India, has been devoting considerable attention to the subject in "Professional Paper No. 12, Survey of India," a summary of which is given in *The Observatory* for November, 1912, p. 413:

"It may be remembered that several years ago Col. Burrard showed that there appears to be a subterranean mass of great density lying across India in mean latitude 23° North. He now shows that the observations indicate the existence of a line of low density between this subterranean mass and the Himalayas, and suggests that there was, or is, one long crack in the earth's subcrust extending from Sumatra round the Arrakan coast across northern India, through the Persian Gulf to the Mediterranean, traces of which are seen in the parallel shores of the Gulf of Oman and the Persian Gulf. The crack has been filled with alluvial deposit across Northern India and in other places, but the Himalayas remain as the result of the rift in the earth, a great mass of matter having been pushed northward. It has been supposed by others that the Himalayan range was formed by the southward advance of the northern part of the Asiatic continent on to the Indo-African tableland."

The idea here developed by Colonel Burrard, including especially the light material under northern India, and the pushing of the Himalayas northward, is so very similar to that developed in my memoirs that it must be regarded as an independent confirmation of the theory that the mountains are formed by the sea. And as this conclusion applies to the greatest and most intricate range in the world, the external relations of which are not entirely simple, I deem it worthy of attention.

Finally, it may be noted that much interest has been awakened in this subject in England and other countries of Europe. The new theory already is widely taught in the schools of Great Britain and the continent; and in his new work "The Growth of a Planet" (The MacMillan Co., New York, 1911), the London geophysicist Mr. Edwin Sharpe Grew, M.A., concedes that the author's reasoning on the Aleutian Islands is unanswerable, and finally says:

* Since this paper was written Colonel Burrard informs me that to his regret he had not seen the papers of 1906–8, and seems to regard the new theory as quite well established.

"Dr. See has arranged his facts with great ingenuity, and the presentation of his case is the most powerful argument which has ever been advanced in favor of the view held since the days of Strabo, Aristotle or Pliny, that the expansive force of steam is the prime cause of volcanic and seismic disturbances."

In view of this general interest a few additional considerations on the origin of the Himalayas may be important. For after careful reflection I regard the Himalayas as the crucial test; and as the theory is triumphantly verified by a more complete study of this great range, it must hereafter be regarded as firmly and permanently established.

2. The Volumes of the Plateaus of the Rocky Mountains, of the Andes, and of the Himalayas.

In the four memoirs included in the *Proceedings* of this Society for 1906–08, the new theory of mountain formation is treated with considerable detail, but some numerical relations between the plateaus above mentioned are worthy of more attention than they have yet received.

The Pacific plateau of North America is of variable width, being less than 500 miles wide in Mexico, and perhaps 600 miles wide in Canada, but from 1,000 to 1,500 miles wide in the United States. Perhaps 750 miles wide would be a good average estimate of the whole plateau. And the height may be taken as approximately 5,000 feet, or a mile above the sea. These average figures will satisfactorily represent the Pacific plateau in North America. It is noticed also in many places that where the plateau is broadest it is of less average height; but where it is narrower the height is somewhat increased.

In the Andes the same principles prevail. The plateau is highest in the region of Lake Titicaca, where the elevation is over 12,600 feet, or 2.5 miles. The width here does not exceed 300 miles. Further north, near Quito, it narrows up, and is not over half this width; but in Colombia it again spreads out to a width of 300 or 400 miles, but is only about 6,000 or 8,000 feet in height, scarcely more than half that along the more southern portion of the Andes.

It is noticeable that the height decreases from 12,600 feet near Lake Titicaca, to 11,000 feet in central Peru, and perhaps 10,000 feet at Quito; while south of Titicaca the height does not decrease appreciably till central Chile is reached, after which it falls steadily till the continent sinks beneath the sea at Cape Horn.

Now it is remarkable that if we take a typical section of the highest and broadest part of the Andean plateau, 2.5 miles high by 300 miles wide, the numerical product of width by height in miles is 750. And the Rocky Mountain plateau, 1 mile high and 750 miles wide, gives the same product, 750 square miles.

To be sure this product can be varied considerably by taking different sections of the plateaus of North and South America, but all in all this average estimate appears to be a fair one. For in the article "Andes," in the encyclopedia Britannica, 9th edition, Sir Archibald Geikie estimates the bulk of the Andes as of the average width of 100 miles, and height of 13,000 feet. The present estimate gives greater width but somewhat less height.

On the whole, I am inclined to think that the average sectional volume of the Andes is somewhat less than that in the Rocky Mountain plateau; for between Colorado and the Pacific coast the width is about 1,500 miles, and the average height about a mile. The plateau is much narrower in Canada, and very much narrower in Mexico, practically disappearing entirely in Central America and Panama. Thus at one point in the United States the sectional contents may be twice that in the Andes; yet the average sectional volume for the Pacific plateau of North America is not much greater than the larger sectional volumes for the plateau of the Andes.

The significance of this equality in the volumes of the two plateaus lies in the fact that both are the product of the common Pacific Ocean, one in the northern, the other in the southern continent. The new theory does not require that the volumes should be exactly equal, but it implies that they should be comparable, and such is the fact in a very striking degree.

Let us now consider the plateau of Tibet, in comparison with that of the Andes. The height of western Tibet is about 15,000 feet, while eastern Tibet has an elevation of only 11,000 feet. The breadth also varies from some 200 miles on the West to 500 miles at the eastern extremity (General Strachey, article "Himalayas," Encyclopedia Britannica, 9th edition).

Accordingly, if we take the wider part of western Tibet as having a sectional height of 3 miles and a breadth of 250 miles, the product in miles is 750, exactly the same as in the Andes and the Rocky Mountains. Further east in Tibet the width may be 500 miles, and the height about 2 miles, which gives a sectional product of 1,000. This is larger than the average Andean product adopted above, and more like that of the Rocky Mountain plateau west of Colorado.

But the circumstance that the sectional volumes of three great plateaus in the three leading continents of the globe should all be so nearly equal is fully as impressive a fact as the related fact that all of these plateaus should overlook the same great ocean by which they were elevated.

Altogether the similarity in the volumes of sections of these three greatest plateaus is so striking as to make it difficult to deny that it constitutes practically a mathematical demonstration that these plateaus were uplifted by the Pacific Ocean. The relationships here brought out as to the volumes of these plateaus, in addition to the situations about the Pacific Ocean could not well be accounted for by chance, even if we did not know the cause of mountain formation. But as the cause of mountain formation is fully understood, the cause which has built the plateaus is also clearly shown, and it is impossible to consider any other explanation than that here outlined.

3. General Law that where a Continuous Plateau Increases in Width, it Decreases in Elevation.

This law doubtless results from the process of uplifting by which the mountains and plateaus have been raised above the sea. For example, in case of the continuous plateau crowned with mountain crests which surrounds the Pacific Ocean from Cape Horn to Alaska, and then extends down the southeastern shores of Asia, runs westward through India, and down the east shore of Africa to the Cape of Good Hope, it is observed in each of the four continents traversed that where the plateau is highest it usually narrows in width, and *vice versa*.

Thus we have seen that the plateau of the Andes is high in Chile, Bolivia, Peru and Ecuador, but in Colombia falls to about half its former level, and expands to about double width. This expansion of the width of the plateau in Colombia is characteristic of plateau formation in general. There are slight exceptions to the rule, but the conformity to it is much more noticeable. For example, at Titicaca the width is about 250 miles, but some distance north of this region the Andean Plateau seems to narrow up till the width scarcely exceeds 150 miles, in Ecuador; but it then spreads out again as the range enters Colombia.

It is not easy to explain this narrowing of the range, unless the great width and great height at Titicaca are due to the indentation of the coast at this point, giving uplifting forces from both directions, at the same time. This explanation seems to be well founded, and is confirmed by the corresponding effect north of central India, where the plateau of Tibet reaches its maximum elevation.

Accordingly, we probably should conclude that the width of the Andean plateau is normally less than at Lake Titicaca, and that the width there is due to a combination of forces from the two lines of coast, meeting at an angle of about 135°. It is therefore a fact in South America that wherever the plateau is widest, it decreases in elevation, as in Colombia.

In this problem of uplift, however, something depends on the depth and width of the adjacent elevating ocean, and thus a certain amount of variety should result. Since the adjacent sea is not of uniform effectiveness, we should expect minor deviations from the law; but obviously they should not be too pronounced.

In North America, the same general law holds true. Wherever the plateau is narrow, as in central Mexico, the elevation is great; but where it is wide, the elevation generally is lower. There are of course some exceptions to the rule, but it generally holds true.

For example, along the Rocky Mountain range the highest part of the plateau probably is in Colorado, where the whole Pacific plateau is widest; but this only indicates that the forces which raised such high mountains as Pike's Peak also raised a high plateau in the general region, independent of the width of the plateau afterwards elevated from the sea. And so on generally.

The rule that the plateau decreases in height when it increases in width, must be understood to apply to a region of not too great width. For when the width is very great, we have rather a series of plateaus added together side by side than a single one; and the final result is a composite effect, one *plateau section* fitting onto another, and the whole series of sections running together as an unbroken embankment of variable height.

In view of these considerations, a plateau so wide as that between Colorado and California is really a series of plateaus, each of unusual width at this point, and the whole effect therefore a very broad compound plateau. The entire Pacific Plateau is the cumulative work of the ocean, done in successive sections; and as the ocean is deepest opposite California, the uplift naturally has been greatest in this part, which also developed the Sierra Nevada Mountains, and at a still earlier stage the Wasatch range in Utah.

The history of the building of the Pacific plateau from Colorado to California is too long to be described here, but these hints on the method by which it was elevated give some idea of the growth of the continent westward from the ancient border which was east of the present Rocky Mountain range.

4. The Cause of the Great Height of the Plateaus of Western Tibet and Titicaca.

Since writing the memoirs of 1906–08, I have had occasion to reëxamine the relationships of the great mountains to the plateaus, and of the plateaus to the sea, with the result of confirming in the most conclusive manner the uplift of the plateaus by the ocean. It is found that the plateau of western Tibet has almost exactly the relationship to the ancient sea valley formerly covering northern India, that the plateau of Titicaca now has to the border of the Pacific Ocean.

If we examine a good map of northern India, we shall find not only that the Indus and Ganges now flow in the ancient sea valley formerly depressed below the waves, and now elevated less than 1,000 feet above the ocean; but also that this valley made a sharp bend in north central India. It has the form of the Greek letter lambda, Λ, with the Ganges leg of the lambda by far the longest, and the included angle about 105°.

If the lava expelled from beneath this ancient sea valley came from two directions, at such an angle, the forces of uplift naturally would accumulate at the head of the Sea Valley. For they would come from the southeast and also from the southwest, as well as from the south; and the result of compounding these forces would be magnified forces of unusual intensity, directed to the elevation of the Himalayas of north central India. This is exactly what has taken place; and hence we see why the plateau of Tibet is so high in the western part of that great "roof of the world."

If now we turn to the region of Lake Titicaca, in South America, we find an exactly similar relative situation. The coast from the south and northwest meet at an angle of some 135°; and the forces producing the uplift have come from the two directions; and also from the west. The result has been a convergence of the forces tending to produce an uplift; but as the angle of 135° is less acute than in northern India, where the angle is 105°, it is not remarkable that the plateau of Titicaca is less elevated than that of western Tibet, where the forces converged more powerfully and were so compounded as to produce the maximum elevation.

It certainly is not accidental that these two highest plateaus of the world stand in *similar centers of converging forces directed from the ocean;* and that the higher plateau of Western Tibet has the forces converging at the smaller angle of 105°, and therefore compounding more effectively to produce a greater power of uplift, for equal energy directed from the side of the sea.

And as the observed phenomena confirm the theory in every detail, one finds it very difficult to believe that any other cause has shaped these stupendous uplifts of the earth's crust.

It is also easy to see why the heights of the plateau of Tibet is less towards the east, where the elevation is only 11,000 feet. For in the eastern part only a side pressure was available for the uplift, and the forces of elevation did not converge towards a point, as in western Tibet and near Lake Titicaca, in Bolivia.

5. Some Phenomena Connected with the Great Earthquake at Arica, August 13, 1868.

One of the most important means of judging of earthquake phenomena is the evidence afforded by eye witnesses; and this becomes especially valuable when we know the nature of earthquake processes, because it then becomes possible to see in the descriptions given by eye-witnesses a certain amount of new meaning.

Accordingly, we add a brief account of the terrible earthquake at Arica, August 13, 1868, which was a continuation of the movements directly concerned with the uplift of the plateau of Titicaca. For it was a survival of the ancient movements which brought about this elevation, and as the region still is near the sea, it is of special interest, because it bears on the elevation of the plateaus of the Himalayas, now further inland.

In his "Light Science for Leisure Hours," p. 199, the late Professor R. A. Proctor describes the havoc wrought by the earthquake at the neighboring town of Arequipa as follows:

> "At five minutes past five (P. M.) an earthquake shock was experienced, which, though severe, seems to have worked very little mischief. Half a minute later, however, a terrible noise was heard beneath the earth; a second shock more violent than the first was felt; and then began a swaying motion, gradually increasing in intensity. In the course of the first minute this motion had become so violent that the inhabitants ran in terror out of their houses into the streets and squares. In the next two minutes the swaying movement has so increased that the more lightly built houses were cast to the ground, and the flying people could scarcely keep their feet. 'And now,' says Von Tschudi, 'there followed during two or three minutes a terrible scene. The swaying motion which had hitherto prevailed changed into fierce vertical upheaval. The subterranean roaring increased in the most terrifying manner: then were heard the heart-piercing shrieks of the wretched people, the bursting of walls, the crashing fall of houses and churches, while over all rolled thick clouds of a yellowish-black dust, which, had they been poured forth many minutes longer, would have suffocated thousands.' Although the shocks had lasted but a few minutes, the whole town was

destroyed. Not one building remained uninjured, and there were few which did not lie in shapeless heaps of ruins."

This description was drawn for the phenomena observed at Arequipa, but that it would serve equally well for Arica is sufficiently indicated by the accompanying photographs of the town as it was before and after the earthquake. A more terrible record of desolation could hardly be imagined.

With this brief but striking description of the earthquake, we may now turn to the seismic sea wave at Arica, and here I shall again quote Proctor's account, which is based on the elaborate technical memoir prepared by Professor F. Von Hochstetter in the *Sitzungsberichte* of the Vienna Academy of Sciences for 1868, Vol. LVIII., Abth. II. Proctor's account runs thus:

"At Arica the sea wave produced even more destructive effects than had been caused by the earthquake. About twenty minutes after the first earthshock (*i. e.*, 5:25 P. M.) the sea was seen to retire, as if about to leave the shores wholly dry; but presently its waters returned with tremendous force. A mighty wave, whose length seemed immeasurable, was seen advancing like a dark wall upon the unfortunate town, a large part of which was overwhelmed by it. Two ships, the Peruvian corvette *America* and the United States 'double-ender' *Wateree* were carried nearly half a mile to the north of Arica, beyond the railroad which runs to Tacna, and there left stranded high and dry. This enormous wave was considered by the English Vice-Consul at Arica to have been fully fifty feet in height.

At Chala, three such waves swept in after the first shocks of earthquake. They overflowed nearly the whole of the town, the sea passing more than half a mile beyond its usual limits.

At Islay and Iquique similar phenomena were manifested. At the former town the sea flowed in no less than five times, and each time with greater force. Afterwards the motion gradually diminished, but even an hour and a half after the commencement of this strange disturbance, the waves still ran forty feet above the ordinary level. At Iquique, the people beheld the inrushing wave whilst it was still a great way off. A dark blue mass of water, some fifty feet in height, was seen sweeping in upon the town with inconceivable rapidity. An island lying before the harbor was completely submerged by the great wave, which still came rushing on, black with the mud and slime it had swept from the sea bottom. Those who witnessed its progress from the upper balconies of their houses, and presently saw its black mass close beneath their feet, looked on their safety as a miracle. Many buildings were indeed washed away, and in the lowlying parts of the town there was a terrible loss of life. After passing far inland the wave slowly returned seawards, and strangely enough, the sea, which elsewhere heaved and tossed for hours after the first great wave had swept over it, here came soon to rest.

At Callao a yet more singular instance was afforded of the effect which circumstances may have upon the motion of the sea after a great earthquake has disturbed it. In former earthquakes Callao has suffered terribly from the effects of the great sea-wave. In fact, on two occasions the whole town has been destroyed, and nearly all its inhabitants have been drowned, through the inrush of precisely such waves as flowed into the ports of Arica and Chala. But upon this occasion the center of subterranean disturbance must have been so situated that either the wave was diverted from Callao, or more probably two waves reached Callao from different sources and at different times, so that the two undulations partly counteracted each other. Certain it is that although the water retreated strangely from the coast near Callao, insomuch that a wide tract of the sea-bottom was uncovered, there was no inrushing wave comparable with those described above. The sea afterwards rose and fell in an irregular manner, a circumstance confirming the supposition that the disturbance was caused by two distinct oscillations. Six hours after the occurrence of the earth-shock, the double oscillations seem for awhile to have worked themselves into unison, for at this time three considerable waves rolled in upon the town. But clearly these waves must not be compared with those which in other instances had made their appearance within half an hour of the earth-throes. There is little reason to doubt that if the separate oscillations had reinforced each other earlier, Callao would have been completely destroyed. As it was, a considerable amount of mischief was effected; but the motion of the sea presently became irregular again, and so continued until the morning of August 14, when it began to ebb with some regularity. But during the 14th there were occasional renewals of the irregular motion, and several days elapsed before the regular ebb and flow of the sea were resumed."

In this excellent account of the great sea wave at Arica, August 13, 1868, Proctor makes no allusion to the U. S. S. *Fredonia*, which was lying at anchor with the *Wateree;* and we add therefore that the *Fredonia* is reported to have been capsized as the wave advanced, and nothing was ever again heard of her, all the officers and crew having been lost with the wreck of the vessel.

The *Wateree* was but little injured, and afterwards used as a hotel. The picture of the stranded *Wateree* here reproduced was made by an officer who visited the scene sometime after the disaster. This valuable historic photograph has been preserved by Mrs. E. V. Cutts, of Mare Island, to whom the author is indebted for this impressive illustration of the effects of this great sea wave.

The previous illustrations show the city of Arica before this earthquake, and the mere wreckage which remained after the innundation of the sea.

In an earlier passage than that above cited, Proctor quotes the description of an eye witness, which tells of the movements of the ships:

"The agent of the Pacific Steam Navigation Company, whose house had been destroyed by the earth-shock, saw the great sea-wave while he was flying towards the hills. He writes: 'While passing towards the hills, with the earth shaking, a great cry went up to heaven. The sea had retired. On clearing the town, I looked back and saw that the vessels were being carried irresistibly seawards. In a few minutes the sea stopped, and then arose a mighty wave fifty feet high, and came in with a fearful rush, carrying everything before it in terrible majesty. The whole of the shipping came back, speeding towards inevitable doom. In a few minutes all was completed—every vessel was either on shore or bottom upwards.'"

6. Pratt's Reasoning on the Density of the Matter Under the Ocean, Plains and Mountains, and its Application to India and the Himalayas.

Pratt's reasoning in regard to the density of the matter in and beneath the crust of the earth, and its bearing on the new theory of earthquakes is described in my paper on "The Cause of Earthquakes, Mountain Formation and Kindred Phenomena Connected with the Physics of the Earth," published in the *Proceedings* of this Society for 1906, pp. 344–346. His main conclusion is stated thus:

"This (deflection of the plumb line) shows that the effect of variations of density in the crust must be very great in order to bring about this near compensation. In fact the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean-bed" (Pratt, "Figure of the Earth," 3d edition, Art. 137, pp. 134–135).

Again:

"The conclusion at which we have arrived in Art. 137, that the parts of the crust below the more elevated regions are of less density, and the parts beneath the depressed regions in the ocean are of greater density than the average portions of the surface, seems to bear additional testimony to the fluid theory. For it shows that notwithstanding the varied surface, seen at present in mountains and oceans, the amount of matter in a vertical prism drawn down at various places to any given spheroidal stratum is the same, although its length varies from place to place as the earth's contour varies" (idem., p. 162).

This subject of the density of the matter hidden from our view beneath the crust of the earth has also been discussed by the late Professor Henri Poincaré, in an address on "French Geodesy," translated by Professor George Bruce Halstead, and published in the *Popular Science Monthly* for February, 1913. The eminent French geometer reasons as follows:

"But these deep-lying rocks we cannot reach exercise from afar their attraction which operates upon the pendulum and deforms the terrestrial spheroid. Geodesy can therefore weigh them from afar, so to speak, and tell us of their distribution. Thus will it make us really see those regions which Jules Verne only showed us in imagination."

"This is not an empty illusion. M. Faye, comparing all the measurements, has reached a result well calculated to surprise us. Under the oceans, in the depths, are rocks of very great density; under the continents, on the contrary, are empty spaces."

"New observations will modify perhaps the details of these conclusions."

"In any case, our venerated dean has shown us where to search and what the geodesist may teach the geologist, desirous of knowing the interior constitution of the earth, and even the thinker wishing to sepculate upon the past and the origin of this planet."

From this extract it will be seen that the most eminent French authorities recognize the conclusions first formulated by Pratt over half a century ago. It only remains to consider the application of Pratt's theorem to the Himalayas and the plateau of Tibet.

If, as Pratt says, "the density of the crust beneath the mountains must be less than that below the plains, and still less than that below the ocean bed," it is very difficult to see how this could have come about except by the greater uplift of the mountains, by the injection of more light material beneath, while a less amount of such material has been injected under the plains, and scarcely any has remained under the ocean bed, because it tends to work out by the path of least resistance. This is the only explanation which satisfies the observed phenomena, and conforms to the known fact that the mountains and plateaus are uplifted by the expulsion of matter from beneath the sea, in world-shaking earthquakes. Thus the known facts of geodesy as respects the Himalayas are fully explained. And the explanation rests on principles established by a variety of mutually confirmatory observations.

7. Defects in the Doctrine of Isostacy as Commonly Stated.

The doctrine of isostacy as commonly stated is vitiated by a serious if not fatal error; and it is necessary to overcome this defect if the doctrine is to hold its place in modern thought. In *Science* of February 10, 1911, Professor J. F. Hayford presents a paper based on the valuable data he obtained in the work of the U. S. Coast and Geodetic Survey, deduced from 765 series of astronomical observations at 89 stations in the United States. The causes assigned, however, are so inadequate that it seems worth while to point out the defects in his reasoning, which is as follows:

"Columns *A* and *B* have been assumed to contain equal masses. There is complete isostatic compensation. The pressures at the bases of the two columns are equal, and at any less depth, *X*, the pressure is greater in *A* than in *B*. Now assume that in the normal course of events a large amount of material is being eroded from the high surface of column *A* and deposited on the low surface of column *B*. After this erosion has been in progress

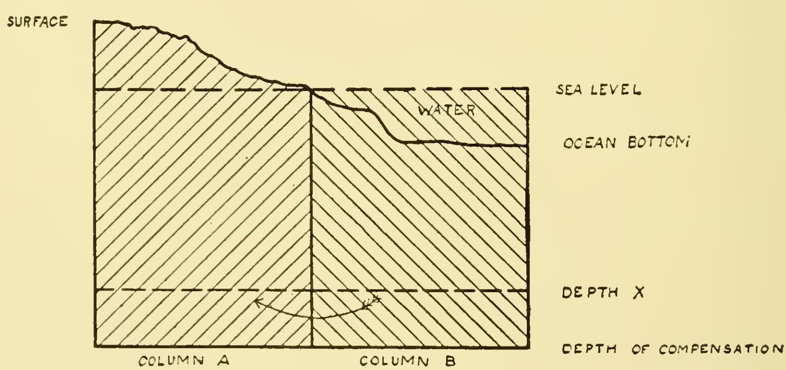

Fig. 1

for some time the isostatic compensation will no longer be perfect. The pressure at the base of *B* will be greater than at the base of *A*. The pressure very near the top of *B* will still be less than at the same level in *A* so long as the top of *A* remains higher than the top of *B*. There will be some intermediate level at which the pressure in the two columns is the same.

Call this level of temporary equality of pressure in the two columns the neutral level. As the process of erosion and deposition progresses the neutral level will gradually progress upward from its original position at the base of the columns. Eventually if no interchange of mass took place between the columns except at the surface, and no vertical displacement occurred in either column, the neutral level would reach the surface when the process of erosion and deposition became complete and the upper surfaces of the two columns were at the same level. During the process of erosion and deposition the excess of pressure in *A* at any level above the neutral level will continually decrease. Similarly, at any level below the neutral level the excess of pressure in *B* will continually increase as the erosion progresses and the neutral level will rise. Thus there will be established a continually increasing tendency for the material below the neutral level in *B* to be squeezed over into *A*. If the stresses tending to produce this undertow from the lower part of *B* to *A* become greater than the material can stand, the flow will take place as indicated by the arrow in the figure. If the material flows without change of volume, as if it were incompressible, the upper part of *A* and its surface will be raised, the upper part of *B* and its surface will be lowered, the neutral level will sink and an approximation to the original conditions with complete isostatic compensation will be re-established."

"This is the general case of isostatic readjustment by the action of gravitation alone. Gravitation tends to produce a deep undertow from the regions where deposition is taking place to the regions where erosion is in progress, in the direction opposite to that of the surface transfer of material."

"Let us suppose that the isostatic compensation at a given stage in the earth's history is practically complete for a continent, that the process of erosion from the greater part of the continent and deposition around its margins is in progress, and that the process of readjustment by a deep undertow is in progress."

The fatal defect in this reasoning consists in the fact that it begs the question, and does not in any way explain the elevation of the margin of a continent, but only how it may maintain its present form by a process of readjustment. This is like a river rising higher than its source, or a man trying to lift himself by pulling on his bootstraps, or the logician reasoning in a circle. For in order to explain the development of the inequalities of the earth's crust, we must not only explain the adjustment and balancing between adjacent parts, but also *how the original uplift came about,* to give the observed contrast in surface levels.

Now on the premises used by Hayford, it is possible to explain how a given inequality of surface levels, when once existing, *can* *be maintained;* but it is not possible to account for the *origin of the inequalities of level. Isostacy as thus depicted is not an active creative agency, but simply a negative process for maintaining existing inequalities.* Under the doctrine as above stated, the height of a mountain or plateau could never increase, for that would require the exertion of positive elevating forces, not mere balancing for maintaining inequalities of levels already existing.

Accordingly, this formulation of the doctrine of isostacy is defective, and inadequate to account for the phenomena of the earth's crust.

The true doctrine should include not only the *balancing process* described by Hayford, but also those *elevating forces directed from the sea*, by which the mountains are elevated as narrow walls about the borders of continents, on the great plateaus which spread out as wider embankments beneath them. Without these positive uplifting forces, no continent could ever have a mountainous border thrown up about it.

No doubt the elevation is produced under approximately isostatic conditions. Mountains can be forced up only to a certain height, the transfer of lighter material under the higher parts thus giving nearly equal mass in all equal prisms drawn to the center of the earth. The path of least resistance is towards regions of elevation, and the underlying material expands as the surface level is forced up. If this were not so the greater weight under the elevated region would cause it to subside to the common level. In this way, and in this way only, can progressive elevation be produced.

The weakness of the old method of reasoning is further illustrated by Hayford's remarks:

"Under a region of deposition two effects of opposite sign tend to occur. The effect of increased pressure tends to produce chemical changes accompanied by decrease of volume and so to produce a sinking of the surface. The blanket of deposited material tends to raise the temperature in each part of the material covered, to increase the volume of this material, and thereby to raise the surface. The temperature effect may serve in time to arrest the subsidence caused by increased pressure or even to raise the surface and change the region of deposition into one of erosion."

"The changes of temperature just described are due directly to erosion

RELIEF MAP OF THE TERRESTRIAL GLOBE.

Illustrating the relations of the mountains to the sea, which has uplifted great walls along the borders of the Continents, by the expulsion of lava from beneath the ocean and its injection under the land. This impressive view of the Earth shows at a glance that the mountains have been formed by the Sea. From Frye's *Complete Geography*, by permission of Ginn & Co., Publishers.

and deposition. If as an effect of erosion and deposition an undertow is started tending to reëstablish the isostatic condition, this undertow, a flow of material presumably solid, necessarily develops considerable heat by internal friction. The increase of temperature so produced tends to cause an increase of volume. It may favor new chemical changes, including changes from the solid to the liquid state, which may be accompanied by a change of volume. The undertow tends to be strongest not under the region of rapid deposition, but under the comparatively neutral region between the two in which neither erosion nor deposition is much in excess of the other, see Fig. 2. Hence the undertow by increasing the temperature and causing a change of density may be directly effective in changing the elevation of the neutral region between two regions of deposition and erosion."

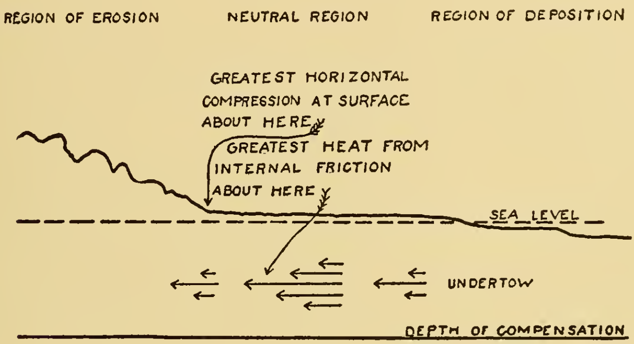

Fig. 2

"Horizontal compressive stresses in the material near the surface above the undertow are necessarily caused by the undertow. For the undertow necessarily tends to carry the surface along with it and so pushes this surface material against that in the region of erosion, see Fig. 2. These stresses tend to produce a crumpling, crushing and bending of the surface strata accompanied by increase of elevation of the surface. The increase of elevation of the surface so produced will tend to be greatest in the neutral region or near the edge of the region of erosion, not under the region of rapid erosion nor under the region of rapid deposition."

The criticism against this reasoning is the same as that used above—namely, it will explain only balancing, but not the uplifting of great mountain walls along the sea coast. Nothing but the transfer of lava from beneath the sea, and the expansion of it under the mountains will explain the observed mountain walls along the borders of continents; and this requires positive forces of elevation, not mere negative processes. The advocates of isostasy, as heretofore taught, have left that doctrine with such a serious defect that this correction is necessary to give it a rational basis.

8. The Uplifting of the Himalayas, Arrakan and Afghanistan Ranges Explains the Great Asiatic Earthquake belt. Confirmation of Colonel Burrard's impressions that the Himalayas have been Pushed Northward, but not by a Change in the Rotation Period of the Earth.

We have seen that the region now occupied by the rivers Indus and Ganges was formerly a sea valley; and that after the Himalayas were elevated to a great height, the valley itself was slowly raised above the ocean.

If proof is asked that the valleys of the Indus and Ganges were formerly below the sea, it is furnished by the well-established fact that such valleys as the San Joaquin and Sacramento in California were below the sea when the Sierras were being elevated. What has happened in California has also happened in India; and the same process of elevation will eventually give a fertile habitable valley in the belt just south of the Aleutian Islands now covered by a sea nearly five miles deep.

This proof that the valleys of the Indus and Ganges were once several miles beneath the sea level is absolute. For it is definitely known how the mountain ranges and adjacent valleys are crumpled, and finally raised above the sea. And what has happened for mountain ranges in general, has happened also for the Himalayas and the valleys adjacent thereto.

In order to round out the view here traced, it only remains to add that the Arrakan coast of Father India contains two chief mountain chains, one of which is the backbone of the Malay Peninsula; and the other is the range terminating at Cape Negrais, but continuing under the sea in a string of islands, and reappearing further south as Sumatra and Java. The Andaman islands and several volcanoes in the sea appear between Cape Negrais and Sumatra. And both Java and Sumatra are noted for their terrific volcanic violence. This volcanic chain is analogous to that of the Aleutian Islands, except that the middle part is submerged, and the two ends raised above the waves.

The line of thought here developed enables us to understand the volcanic activities of Farther India, and also the terrible belt of earthquakes in Assam and the adjacent regions south of the Himalayas. Part of the ancient sea valley is above the water as low land, and part still in the ocean, and covered by the sea to a considerable depth.

West of India, we have the complicated mountain ranges and earthquake belts of Afghanistan and Persia. It would be difficult if not impossible to understand the phenomena they present if studied alone; but if studied in connection with the developments of India and Farther India above discussed, it is easy to see that Afghanistan and Persia were built up in like manner, and at no very distant epoch were beneath the sea.

In his article on the "Himalayas," Encyclopedia Britannica, 9th edition, the late General Strachey has strongly emphasized the view that the mountains and table lands of Afghanistan and Persia are intelligible only in connection with those of India.

> "It is after the middle Tertiary epoch that the principal elevation of these mountains took place, and about the same time also took place the movements which raised the tablelands of Afghanistan and Persia, and gave southern Asia its existing outlines."

He also points out the fact that at no very distant geological epoch the ocean extended from the Arabian Sea through the Persian Gulf to the Caspian and Mediterranean. The continuation of the earthquake belt through this region of Western Asia is therefore quite intelligible, and the existence of active volcanoes near the Caspian a survival of present and former relations to the ocean.

The annual rainfall south of the Himalayas amounts to about 36 feet, and this is so enormous as to be almost as effective as a shallow sea in keeping alive earthquake processes.

It is established by observation, for example, that the very